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RECENT DEVELOPMENTS IN DEPLOYMENT ANALYSIS SIMULATION USING A MULTI-BODY COMPUTER CODE

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Why Deployment Dynamics Analysis?

Deployment is a candidate mode for construction of structural space system components. By its very nature, deployment is a dynamic event, often involving large angle unfolding of flexible beam members. Validation of proposed designs and conceptual deployment mechanisms is enhanced through analysis. Analysis may be used to determine member loads thus helping to establish deployment rates and deployment control requirements for a given concept. Furthermore, member flexibility, joint free-play, manufacturing tolerances and imperfections can affect the reliability of deployment. Analyses which include these effects can aid in reducing risks associated with a particular concept. Ground tests which can play a similar role to that of analysis are difficult and expensive to perform. Suspension systems just for vibration ground tests of large space structures in a 1 g environment present many challenges. Suspension of a structure which spatially expands is even more challenging. Analysis validation through experimental confirmation on relatively small simple models would permit analytical extrapolation to larger more complex space structures.

- **Deployment: A Candidate For Space Station Construction**
- **Deployment Is a Dynamic Event**
- **Design And Concept Validation**
  - **Determination of Member Loads**
    Deployment Rate
    Deployment Control
  - **Reliability of Deployment Mechanism**
    Flexible Members
    Joint Free–Play
    Tolerances and Imperfections
  - **Ground Tests Difficult and Expensive**
    Suspension System in 1 g Environment
    Size Limitation

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Candidate Multi-Body Programs For Deployment

Shown in this chart is a list of some of the existing U.S. computer programs which are candidates for performing deployment analyses. These programs perform multi-body dynamic analysis. Some of these programs were orignally designed for mechanisms, while others were designed for satellites with appendages. Most of these programs are in a constant state of improvement and most have or will soon have capability for treating flexible members and perhaps sophisticated joint models. However, efficient simulation of a deploying structure with a large number of components will require considerable further development.

ADAMS --------- **Mechanical Dynamics**

ALLFLEX ------ **Lockheed Missiles and Space**

CAPPS -------- TRW

DADS ---------- **University of Iowa**

DISCOS/NBOD -- **Martin Marietta**

IMP ----------- **University of Wisconsin**

LATDYN ------- **NASA (pilot code)**

SNAP ---------- **General Dynamics**

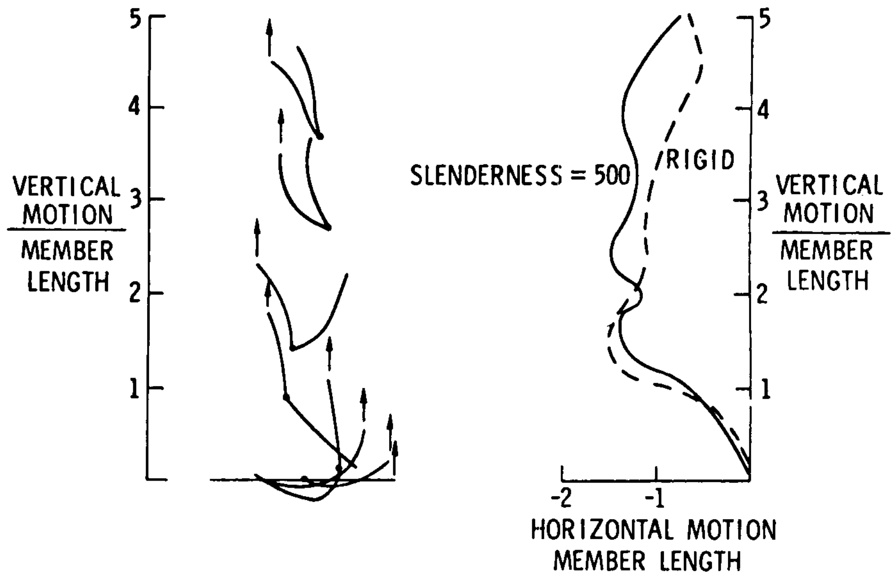
TREETOPS ------ **Honeywell & DYNACS**
& CONTOPS

Cambridge Research Associates Code

OTHER

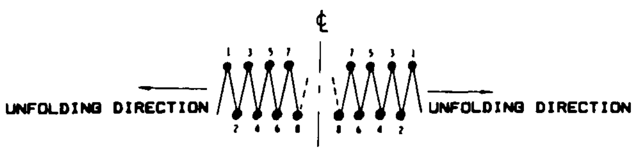
Large Distortion And Motion Of Two Pin-Connected Beams
Subject To A Vertical Tip Step Load

This chart displays the time-lapse response of a generic large motion/large distortion maneuver. Two very flexible beams which are pin-connected at their common end are acted upon by a vertical step load at the free end of one pf the members. Note in the left-hand figure that the pin-connected end first moves downward before moving upward. Also note the large relative angular motions of the members and their distortions. The right hand figure shows the trajectory of the point of load application for both flexible and rigid member cases.

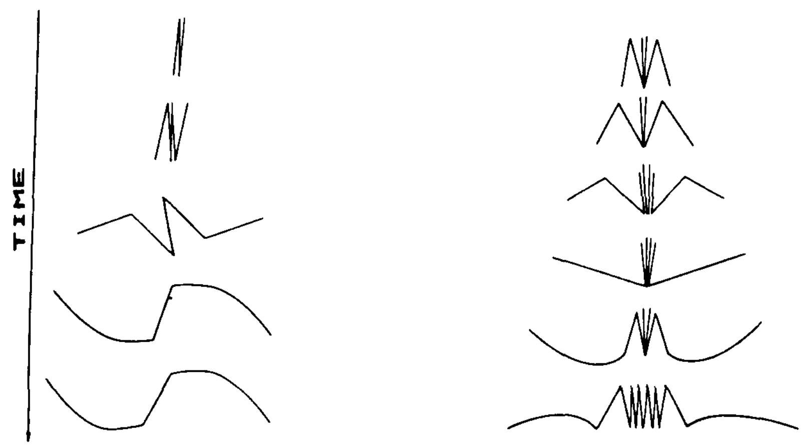


Unfolding Of Multiple Hinged Flexible Beams

This chart displays the unfolding of an accordion-type assemblage of flexible members. The members are hinged together and the deployment is driven by pre-wound torsional springs at each hinge. The deployment sequence of both a five member collection and a sixteen member collection is depicted. Due to the odd number of members in the left-hand portion of the chart, the collection of beams appears rotated. This appearance is explained by an appeal to the conservation of angular momentum. In the right-hand figure, the members are seen to deploy in a near sequential pattern. This is the natural way this system opens up and is not due to a preset adjustment of the driving springs. Rather, the closer a member is to the center of the system, the greater the mass it must push in order to open up. Hence the outer members deploy first and a near-sequential deployment pattern results.



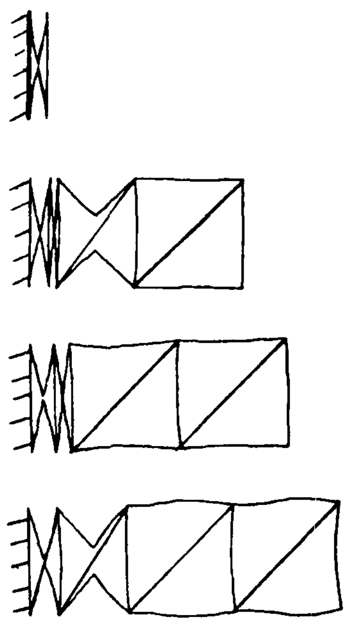
GENERAL UNFOLDING PATTERN



FIVE MEMBERS SIXTEEN MEMBERS

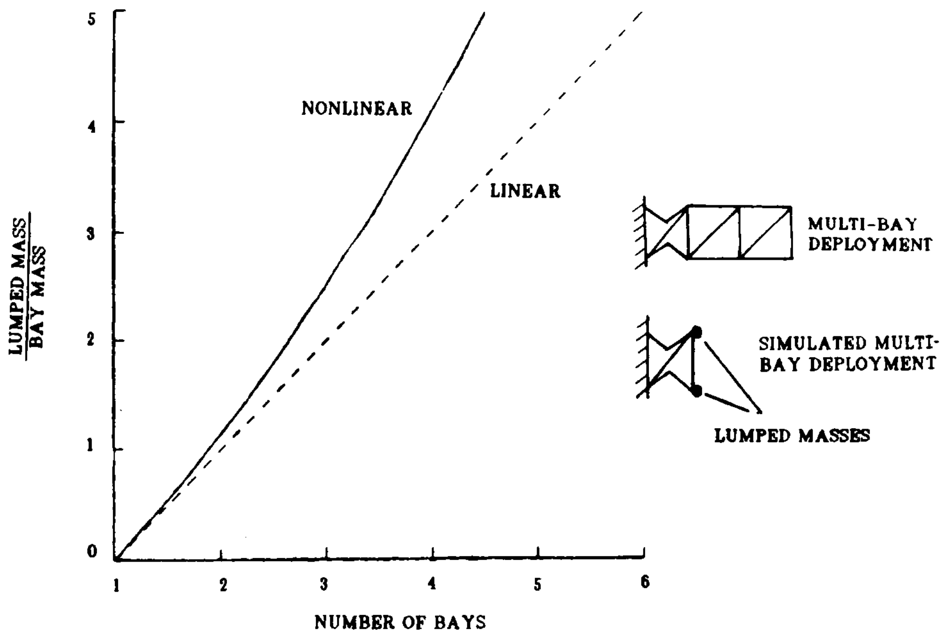
Uncontrolled Deployment Sequence of Four-Bay Mast

In this chart, the analytically simulated deployment of an uncontrolled four-bay mast composed of flexible members is shown. (The analysis was performed using the NASA LATDYN computer program and involved 64 degrees of freedom.) The deployment occurs due to unfolding of the longerons of each bay which have lockable joints midway along their length. The diagonals are assumed to telescope out during the deployment and the deployment is driven by precompressed rotational springs at each lockable joint. Typically such masts are controlled to deploy sequentially, that is, one bay at a time, but an uncontrolled deployment sheds light on the natural deployment character of the design. Moreover, insight is gained into the simultaneous deployment which can occur in other deployables such as a tetrahedral truss. The chart shows that the mast tends to deploy nearly sequentially without control. This appears to be due to the larger inertial mass which must be pushed by the inner bays and to the choice of the spring constants driving the deployment. Thus sequential deployment for a mast tends to be a natural process.



Lumped Mass Necessary to Simulate Uncontrolled Multi-Bay Deployment

Due to the large computational time requirements of the mast deployment in the previous chart, it becomes desirable to simulate the multi-bay deployment using only one bay with lumped masses representing the inertial effect of the remaining bays. The figure shows the amount of lumped mass needed to simulate the deployment time of the multi-bay analysis. The linear curve represents the use of a lumped mass equal to the number of simulated bays. The nonlinear curve indicates the predicted mass needed for this simulation. The linear representation becomes increasingly inaccurate as the number of bays simulated increases and the added mass for multi-bay simulation must be increased.



Uncontrolled Deployment of Flexible Member Hoop

Deployment of a hoop composed of 40 flexible hinged members is considered in this chart. The left-hand figure depicts the hoop deployment sequence. Bending of the hoop members is observable. The right-hand portion of the chart indicates the variation of hoop deployment time with number of hoop members. Two sets of curves are shown. In one set of curves, the length of the hoop members is fixed so that as the number of members increases, the hoop radius also increases. In the second case, the hoop radius is fixed so that as the number of members increases, the member length decreases. Effectively, in the second set of curves, the total weight of the hoop remains fixed. Deployment time is measured from the time the packaged hoop is released to the time all the joints lock up.